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USING A FORCE-FEEDBACK MANIPULATOR

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ABSTRACT

An improved assessment methodology has been implemented at NOSC and tested using an instrumented peg-in-hole (PiH) taskboard. Several aspects of the methodology are discussed in light of their implications for future studies of manipulator performance. Using a simple (but high-fidelity)force-feedback manipulator, a group of 9 trained operators showed a consistent advantage for stereoscopic TV viewing over monoscopic TV viewing when performing the PiH task. To introduce a controlled element of spatial uncertainty into the testing procedure, taskboard orientation relative to the manipulator and remote video camera head was changed in a randomized order on a trial-by-trial basis. The stereoscopic advantage demonstrated by this study can reasonably be expected to be even more pronounced as the quality of the stereo TV interface is improved and force-feedback provided through the manipulator system is diminished and/or distorted.

2. INTRODUCTION

2.1 Is Stereoscopic TV Advantageous for Remote Manipulation?

The controversy continues to this day, seemingly unabated. Nearly 30 years after the earliest published laboratory comparisons of remote manipulation under monoscopic (mono) and stereoscopic (stereo) TV viewing conditions, system designers in a variety of applications areas are still scratching their heads over the question of whether the added expense and complexity of stereo TV are truly worth the investment. It is not difficult to cite several reports in the published literature that support either a "pro or con" stereo TV position. Why has a simple yes or no answer remained so elusive? Because the question, itself, is deceptively simple as commonly stated.

The success or failure of any remote manipulator operation is dependent on three basic aspects of the work situation: 1) the operator , 2) the equipment (including sensors, displays, controllers, effectors, and the datalink) , and 3) the task. Human variability is a given. Operators bring different levels of physical and mental skills to bear on the operation of any manipulator system. How effectively they use their physical and mental resources is strongly conditioned by their previous experiences with the equipment as well as their previous experiences with the task. Stereo TV is, of course, one possible feature of the equipment and there are a great many ways that stereo TV can be implemented, to varying degrees of acceptability. A finding of no performance difference between stereo and mono TV may simply be a matter of poor implementation of the stereo TV equipment or a matter of poor comparability between the stereo and mono systems tested [1]. One might reasonably expect that as overall quality of the equipment improves, that the performance gained by improving one feature of the equipment would diminish. For instance, the stereo TV performance advantage is likely to be less pronounced (but not necessarily less reliable) with a high-fidelity force-feedback manipulator than with one providing no force-feedback. Similarly, as the operators' familiarity with the equipment and the task improves, the performance gain derived from improving a single feature is likely to be less pronounced. Lastly, the particulars of the task to be undertaken and its environmental context have a direct and obvious impact on how well it can be done. The task domain for remote manipulation is ever-growing. Demands for ma-

equivalent manual dexterity from remotely operated manipulators have been on the rise given the phenomenal success of computing technologies and their adaptation into remote manipulation systems. Under most real-world conditions where environmental visibility is adequate, manipulative capability is very directly dependent on the ability to correctly perceive the spatial relationships between the manipulator and the objects to be manipulated. To the extent that stereo TV provides the operator with a more accurate perception of the relative depths of objects as well as their 3-dimensional shapes, one can expect it to produce performance advantages.

A fair, unbiased approach to comparing various features of remote manipulation systems must take into account and experimentally control for influences on performance outcomes arising from all 3 of the major areas of influence outlined above. Such a methodology must be founded on competent engineering practices for design and maintenance of equipment as well as a close adherence to standards for conducting behavioral research [2] and statistical analysis [3] practiced by the social science research community.

2.2 Improvements in Testing Methods at NOSC

During the past year at NOSC-Hawaii, we have improved testing methods for comparing various features of remote manipulation systems. This has involved implementing more rigorous procedures for operator screening and taking greater precautions to isolate operators from extraneous sources of stimulation, both visual and auditory, during test sessions. Data collection is now fully automated, providing better standardization of procedures as well as more precise and completely objective measurements of operator responses. Full automation of the test procedure also makes it convenient to completely randomize orders of presentation of the various conditions or system features to be compared. It supports the utilization of within-subjects test designs while controlling for the potential contamination of carry-over effects. By precisely controlling the position and orientation of a taskboard relative to the sensors and the manipulator arm, it also allows us to introduce and control the effects of positional and orientational uncertainty that, we believe, exert a substantial effect on remote manipulation under real-world operating conditions [6].

Given these improvements to the laboratory facility and testing procedures, we collected performance data which addresses the question of the stereo TV advantage for remote manipulation using a peg-in-hole (PiH) task. The methods, results, and findings of a recent experiment are summarized in the remainder of this report.

2.3 Experimental Issues Tested

The single experiment described herein addressed several issues that bear on the usefulness of stereo displays as well as unique features of the task which was selected to show performance differences. In the process of training operators, we were interested in measuring the amount of practice with the manipulator, PiH task, and viewing system that was necessary before learning effects "levelled off" in the peg movement time data . Next, by having operators use pegs of 2 different diameters, we included a variation in task difficulty that has consistently shown large differences in previous studies [7,8]. This factor was included as a validation of the overall screening, training, and testing procedures. We hypothesized that movement times would be slower for tighter peg-hole tolerances in general accord with Fitt's law. In addition, we hypothesized that stereo TV viewing would provide a performance advantage over mono TV viewing. This finding would essentially replicate and therefore support the findings of a previous study [9] with the same manipulator and a similar task using "highly-practiced operators".By introducing and experimentally controlling for orientational uncertainty of the taskboard on a trial-by-trial basis, we hypothesized that the stereo advantage would be even more pronounced when the taskboard was re-oriented on a trial-by-trial basis than it would when it remained fixed in orientation over a large block of trials. By choosing relatively small deviations of the taskboard from a "normal" position, we hoped to show the potency of the interaction between stereo viewing and orientational uncertainty. Finally, we were interested in measuring the relative efficiencies of remote

manipulation under direct view/remote manipulation and direct view/direct manipulation control conditions.

3. EXPERIMENTAL METHODS

3.1 Operators

Eight male operators and one female operator participated on a voluntary basis. Their ages ranged from 21 to 47 years. Two of the operators had extensive prior experience using the CRL Model-G manipulator, two had some limited experience with another manipulator, and five had never operated a remote manipulator prior to the experiment. All operators were screened for normal visual acuity in both eyes , vertical and lateral phorias, and the ability to fuse stereo images and perceive forms in depth using a standard Armed Forces Vision Tester and random dot stereogram pairs. One of the male operators was left handed. All operators used their right arms and hands to control the manipulator. To deny operators the use of auditory cues produced by the manipulator, contact of the peg with the taskboard, or the robot arm which moved the taskboard, operators inserted plugs (E.A.R.) in their ears and donned a pair of headphones through which "pink noise" was played at sufficient volume to mask external noise sources. This arrangement had the additional virtue of isolating the operators from all forms of auditory distractions in the lab facility (phones ringing, conversations, military aircraft noises). Operators were informed of the purpose of the experiment and were instructed to place greatest emphasis on avoiding errors such as inadvertent collisions or use of excessive force, but to move the peg as quickly as possible.

3.2 Equipment

A pair of black and white CCD video cameras (Pulnix Model TM-540) with 8mm lenses were used. Each provided coverage over a measured horizontal field of view of 53 degrees. Each camera was attached to an adjustable 3-axis (i.e, pan, tilt, and roll) camera mount which permitted a controlled calibration of the camera pair prior to testing. The cameras and their mounts were attached to a heavy-duty tripod, and their position remained fixed throughout all practice and experimental sessions. Cameras were converged to and focussed on the center point of the PiH taskboard which was 1.2 meters distant. Cameras aimed down to the taskboard center with a lookdown angle from horizontal of 10°. Interaxial separation between the converged cameras was fixed at 6.5 cm.

A dual-monitor beamsplitter display with linear polarizer filters (Polaroid HN38) for channel separation was used for the operator's TV view of the task. For those unfamiliar with the general configuration of a beamsplitter stereo display, a detailed description is available in [5]. Monitors were NTSC standard,19" diagonal, color CRT's (Proton Model 600T). Operators wore eyeglasses or eyeglass clip-ons with appropriately oriented polarizer filters to maintain visual channel separation. Special care was taken to ensure that filters on the monitors and eyeglasses were matched to provide true mono or stereo (not pseudostereo) views with minimal "ghosting". Contrast of the taskboard holes with their immediate surrounding was held constant throughout the experiment. The mono view was achieved by matching the axes of polarization of both eyeglass filters with that of a single monitor. For the direct view control conditions which were run during two of the experimental test sessions, operators were required to wear the stereo polarizer eyeglasses or clip-ons to provide greater comparability with TV viewing conditions. For all TV Views, distance from eye to screen was approximately 1.2 meters, providing a horizontal display field of view of approximately 17 degrees. For the direct view/remote manipulation control session, eye to taskboard center distance was approximately 1.8 meters. Approximate values are reported since operators' head movements were not physically constrained during testing.

The manipulator used , a Central Research Laboratories (CRL) Model G mini-master/slave unit, was of the terminus type, where only the end-point forces at the controller handle are fed forward from and back to the operator. Force reflection in this manipulator is achieved mechanically by means of antagonistic cable pairs operating each of the 3 degrees of freedom in the

"arm" and 4 degrees of freedom (counting grip open-close) in the end-effector. The end-effector was a parallel jaw gripper. A gripper lock feature of the manipulator was used to secure the grip on the peg during testing. This eliminated the operator muscular fatigue that would result from having to constantly exert a pincer-type force to hold onto the peg over a long series of trials. During the direct manipulation control session, the operator sat on a chair in front of the taskboard offset to left center of the board so that the right shoulder was aligned to the taskboard center. Eye to taskboard center distance was approximately 70 cm.

The PiH taskboard consisted of 16 stainless-steel holes of 1 cm diameter and 2.5 cm depth arranged in two straight intersecting lines of 8 holes each to form a cross shape. Holes in the arms of the cross were separated from their nearest neighbors by 8 cm. Across the gap at the intersection of the vertical and horizontal arms of the cross, the holes were separated by 16 cm. Faces of the holes were flush with the flat surface of the taskboard and covered with a non-reflective material. A microswitch was positioned at the bottom of each hole to register full insertion of a peg. Two diameters of pegs were used: .75 and .94 cm. The entire taskboard assembly was attached to the end flange of a large industrial robot arm (Unimation Puma 760). Under program control, the robot arm moved the taskboard to one of 8 pre-defined orientations in a randomized order of presentation. The 8 orientations were 3° and 5° "off-normal" in the up, down, left, and right directions. For TV Viewing sessions, the operator's view of the taskboard was blanked out during the period when the taskboard was repositioned prior to each test trial. Three high-intensity incandescent floodlights were positioned above, to the right, and to the left of the taskboard to reduce contrast of the shadows cast on the taskboard during approach to the holes and insertion of the peg.

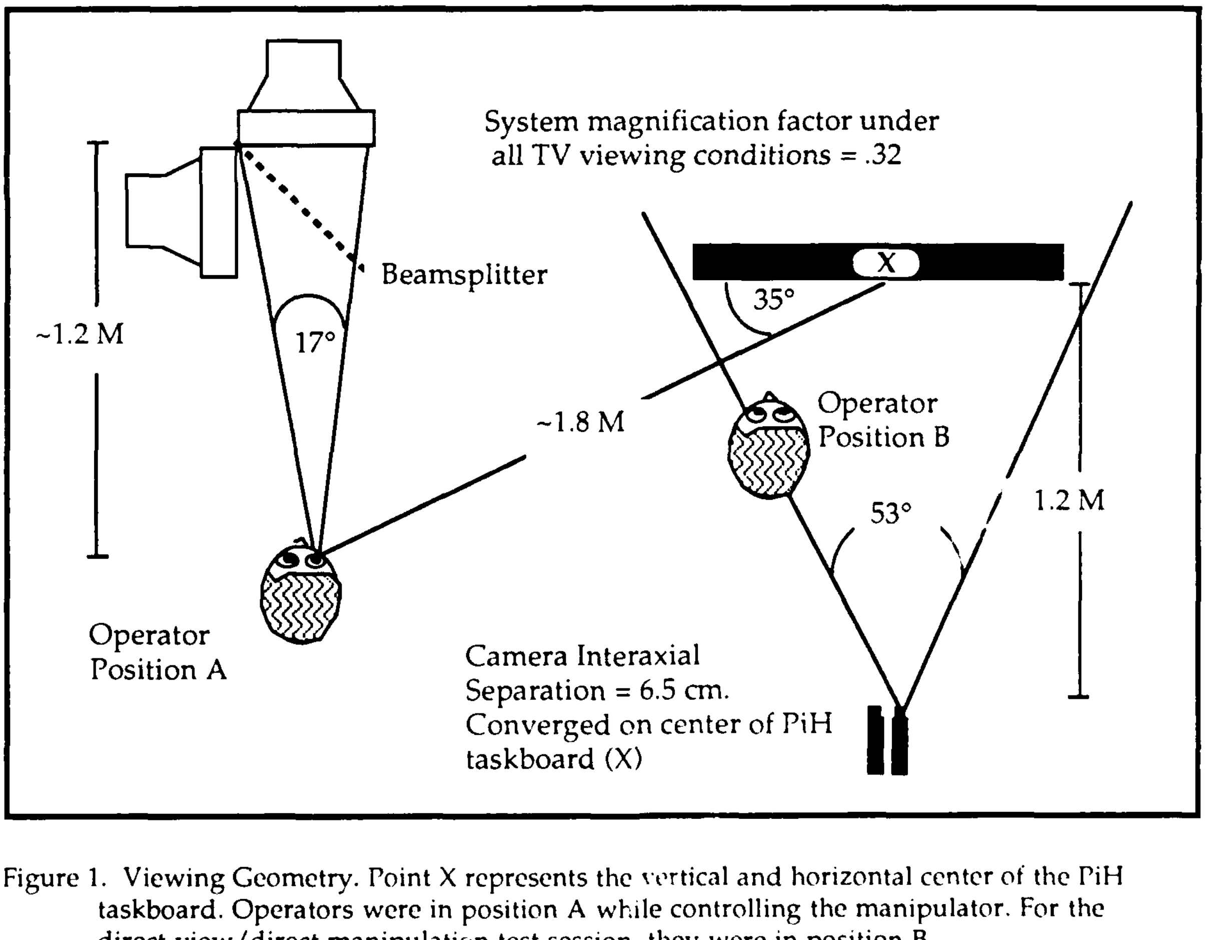


Figure 1. Viewing Geometry. Point X represents the vertical and horizontal center of the PiH taskboard. Operators were in position A while controlling the manipulator. For the direct view/direct manipulation test session, they were in position B.

3.3 Procedure

Prior to experimental data collection, operators were given extensive practice (i.e., two separate test sessions of 128 trials each) in order to familiarize themselves with the manipulator, the task, and the test procedures. Each operator performed one practice session under the mono TV viewing condition and the other under the stereo TV viewing condition. Order of presentation for mono TV viewing and stereo TV viewing was counterbalanced between 2 groups of 4 operators.

For the experiment, each operator was required to perform the peg-in-hole task for six test sessions of 128 trials each. Testing sessions typically required between 60 and 90 minutes to complete. All 6 testing sessions were comprised of trials that measured performance under 2 peg movement directions (vertical vs. horizontal), a single movement distance (24 cm), 2 eccentricities of movement (central and peripheral) and 2 peg diameters (0.75, and 0.94 cm).For the first 64 trials in each session (including practice sessions), the .75 cm diameter peg was used followed by 64 trials in which the .94 cm peg was used. Over the course of the 6 testing sessions, all operators were presented with 2 TV viewing conditions (i.e., stereo and mono), as well as 2 conditions of taskboard orientation (i.e., taskboard fixed and moved). In addition, 2 control sessions were run. In one of these sessions, operators viewed the taskboard directly (i.e., from Position A in Fig. 1) and used the CRL manipulator to perform the task. In the other control session, operators performed the task under direct view conditions (i.e., from Position B in Fig. 1) using their arms and hands. In a "taskboard fixed" session, the PiH board did not change its orientation for the entire set of 128 trials administered. In the fixed orientation, the top of the taskboard was tilted 3° off the vertical axis defined by the "normal" orientation. For the "taskboard moved" condition, the PiH taskboard was changed in orientation from trial to trial. A total of 8 taskboard/manipulator orientations were used. The movement directions and distances were the same for all operators, however the order of presentation was randomized across operators and sessions. Thus, the total set of 768 trials administered during the experiment was the same for all operators, but their order of presentation was both randomized and counterbalanced across operators and sessions to control for learning effects

A single trial was initiated when the operator's prompting CRT indicated the START and END holes which the peg was to be moved between. Once the operator placed the peg into the START hole, the control computer counted-off a 1-second delay, then illuminated a green LED at the control station. This 1-second delay imposed a standard minimal rest period prior to peg movement for all trials. Following illumination of the green LED, the operator lifted the peg out of the START hole, moved it, and inserted it into the END hole. Elapsed time required to move the peg from the bottom of the START hole to the bottom of the END hole was provided as immediate feedback on the operators' prompting CRT and recorded for subsequent analysis.

4. RESULTS

4.1 Practice Effects

To assess the impact of practice effects on PiH task performance over a large number of trials, an analysis was conducted on data derived from the two practice sessions. Movement times for 8 operators were averaged for each of the 256 practice trials. It should be noted that this averaging blurred the distinction between mono and stereo TV viewing since order of presentation of these 2 conditions was counterbalanced for equal-sized groups of operators. Next, a separate linear regression line was fitted to each block of 64 trials, since different-tolerance pegs were used during these blocks of trials. For each of the 4 regression lines thus generated, a test was calculated for the hypothesis that the slope of the best-fit line was zero (i.e., level) . The results of these analyses are summarized in Figure 2. Some overall improvement in performance attributable to practice was noted over the first 3 blocks of trials. The slope of the fourth block was essentially zero.

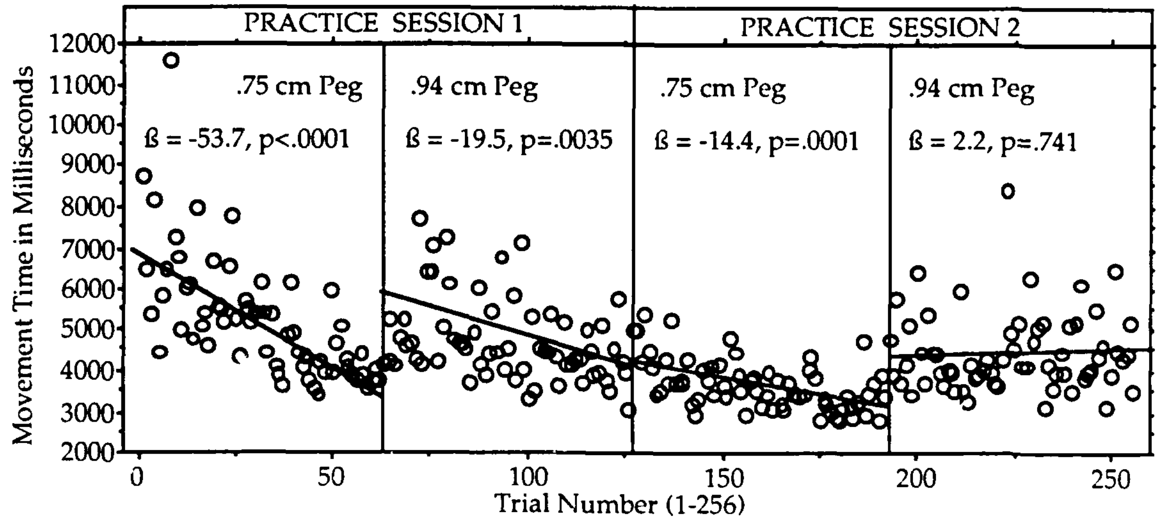


Figure 2. Practice effect for PiH Task performance. Data points plotted are averaged over multiple operators (N=8). For each operator, a total of 256 practice trails were administered in 2 sessions. A regression line was computed for each peg type within each session. Its slope coefficient(ß) and the probability of that slope being zero are reported for each regression line in the figure.

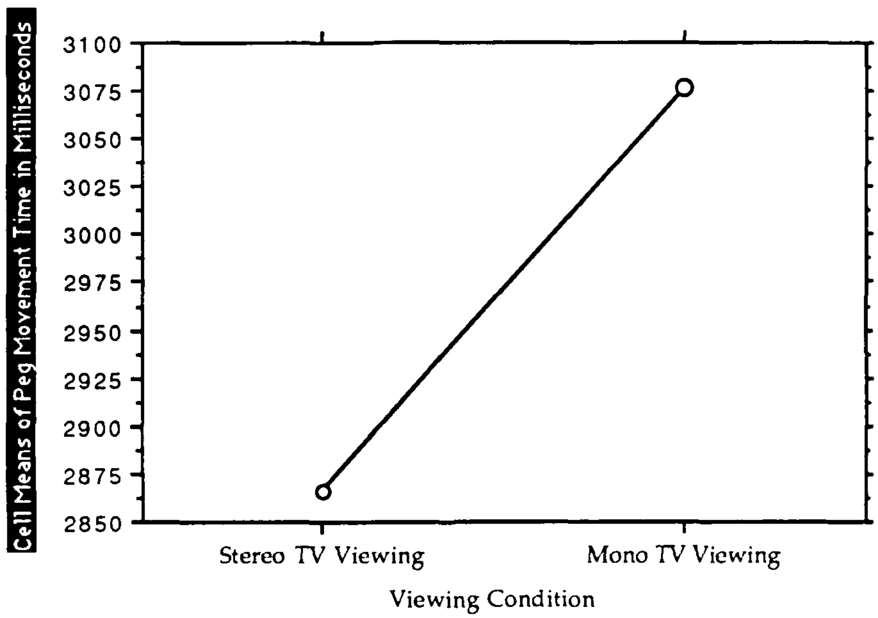
4.2 Stereo TV Viewing Advantage

Peg movement times collected over the total of 54 individual testing sessions were subjected to a 3-way repeated-measures analysis of variance (ANOVA) using a commercially available statistics package [4] to determine the main and interactive effects of viewing condition (stereoscopic or monoscopic), taskboard orientation (fixed or moved), and peg tolerance (2.5 or .6 mm) on PiH movement times. Though the effect for taskboard orientation was in the predicted direction of slower movement times for "taskboard moved" sessions, it was not found to be statistically significant, nor were any of the interaction terms in the 3 factor analysis. The lack of a significant effect for taskboard orientation may well have been due to the use of relatively slight deviations (i.e., 3° and 5°) from the "normal" orientation. A subsequent experiment undertaken in our lab, but not detailed here, used larger deviations (i.e., 10° and 20°) and produced the expected result of a stronger and statistically significant effect for taskboard orientation. For present purposes, however, since no systematic effect for taskboard orientation on movement times was found, the factor was eliminated from further analysis. A subsequent 2-way repeated-measures ANOVA revealed that both viewing condition and peg tolerance exerted statistically significant effects on movement times in the predicted directions. The stereo TV advantage is affirmed in the viewing condition main effect of Table 1 ($F = 15.161$, $p = .0046$, $df = 1$) and in Figure 3. Average task time for stereo TV viewing conditions provided a modest (i.e., 7%) improvement in time required to complete the task, but the effect was highly significant. The main effect for peg tolerance, though not depicted in a figure here, was in the expected direction (i.e., the higher tolerance increased movement times by 21%) and highly significant ($F = 94.518$, $p = .0001$, $df = 1$). No significant interaction was found between the Viewing Condition and Peg Tolerance factors

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Subject	8	13780401.159	1722550.145		
Viewing Condition	1	399829.004	399829.004	15.161	.0046
Viewing Condition * Subject	8	210982.512	26372.814		
Peg Diameter in CM	1	3186759.332	3186759.332	94.518	.0001
Peg Diameter in CM * Subject	8	269728.336	33716.042		
Viewing Condition * Peg Diameter in CM	1	22291.684	22291.684	1.355	.2779
Viewing Condition * Peg Diameter in CM * Subject	8	131586.325	16448.291		

Dependent: Peg Movement Time in Milliseconds

Table 1. Analysis of Variance Source Table for PiH Task Performance Under Stereo and Mono TV Viewing Conditions



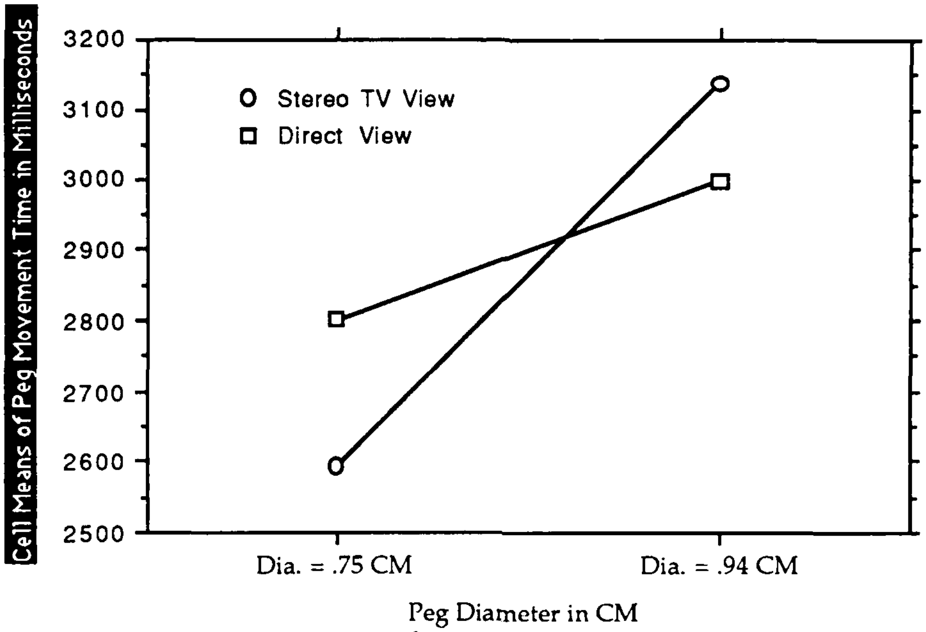
	Count	Mean	Std. Dev.	Std. Error
Stereo TV Viewing	18	2866.149	690.462	162.743
Mono TV Viewing	18	3076.922	747.435	176.172

Figure 3. Plot of PiH Task Performance Under Stereo and Mono TV Viewing Conditions

4.3 PiH Performance With Stereo TV View Versus Direct View

To provide a comparison of PiH performance under stereo TV vs. direct view conditions, a 2-way ANOVA was run on data collected during 2 sessions for each operator: 1) stereo TV view, manipulator used, with the taskboard moved from trial-to-trial, and 2) direct view, manipulator used, with the taskboard moved from trial-to-trial. In both cases, the operator was situated at Position A in Fig. 1.The two factors included in the ANOVA were Viewing Condition (direct view vs stereo TV) and Peg Tolerance. The main effect for Viewing Condition failed to reach statistical significance ($F = 0.21$, $p = .66$, $df = 1$) , but the Peg Tolerance effect was once again found to be highly significant ($F = 29.76$, $p = .0006$, $df = 1$). More importantly, however, the interaction of Peg Tolerance with Viewing Condition was significant ($F = 18.68$, $p = .0025$, $df = 1$). A plot of the cell means for this effect is found in Figure 4. The stereo TV viewing condition was found to yield faster performance times than the direct viewing condition when peg tolerance was low, and slower

performance times when peg tolerance was high. In interpreting this finding, however, it must be remembered, that the angle of regard differed for the 2 views (see Figure 1) in addition to the other differences between TV and direct view conditions.

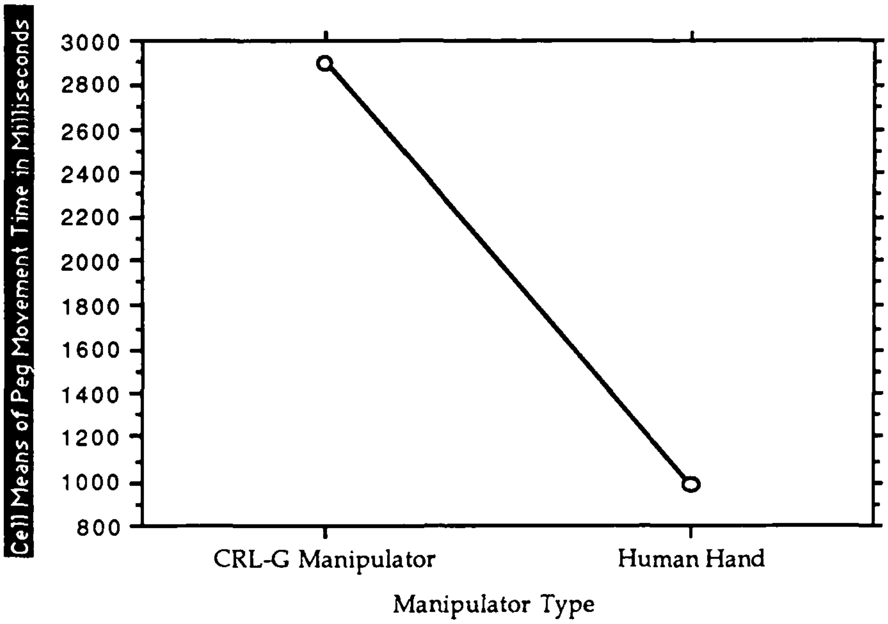


	Count	Mean	Std. Dev.	Std. Error
Stereo TV View, Dia. = .75 CM	9	2593.508	629.981	209.994
Stereo TV View, Dia. = .94 CM	9	3138.790	670.031	223.344
Direct View, Dia. = .75 CM	9	2802.470	711.841	237.280
Direct View, Dia. = .94 CM	9	2996.605	819.715	273.238

Figure 4. Plot of PiH Task Performance with the CRL Manipulator Comparing Direct View with Stereo TV View.

4.4 PiH Performance with Manipulator Versus Human Hand

To provide a comparison of PiH performance with the manipulator vs. human hand, a 2-way ANOVA was run on data collected from 2 sessions for each operator: 1) direct view, human arm and hand used, with the taskboard moved from trial-to-trial, and 2) direct view, manipulator used, with the taskboard moved from trial-to-trial. The 2 factors included in the ANOVA were Manipulation Type (human hand and CRL manipulator) and Peg Tolerance. The analysis yielded highly significant main effects for both factors, but a non-significant interaction ($F = .36$, $p = .56$, df = 1). The contrast between movement times with the human hand and the manipulator ($F = 98.8$, $p < .0001$, df = 1) yielded a near 3-fold increase in performance times in going from hand to manipulator. This effect is depicted in Figure 5. The Peg Tolerance effect ($F = 9.62$, $p = .0146$, df = 1) was once again strong and in the predicted direction of slower response times for the higher tolerance.



	Count	Mean	Std. Dev.	Std. Error
CRL-G Manipulator	18	2899.537	751.422	177.112
Human Hand	18	987.112	224.929	53.016

Figure 5. Plot of PiH Task Performance Comparing Manipulator and Human Hand Under Direct Viewing Conditions

5. CONCLUSIONS

Even though the PiH task used in this study is sometimes regarded as one of the least demanding and easiest of manipulation tasks to master with minimal prior training, the results of the experiment reported here demonstrate that such "conventional wisdom" may be at odds with objective reality. The findings suggest that practice effects can strongly influence performance outcomes for the PiH task over the course of more trials than are frequently given for practice prior to data collection when comparisons of remote manipulation with alternate hardware systems are made. Given adequate controls for carry-over effects (between-operator designs, randomization and/or counterbalancing for orders of presentation), the effects of practice that go on within and across test sessions may not necessarily contaminate or invalidate experimental findings, but they almost certainly will add unaccounted-for variability to the data collected, and this will decrease the likelihood of showing a statistically significant difference between equipment features when such differences do, in fact, exist. Although the practice effects reported here are in the strictest sense described only for the PiH task, they suggest that " more complex" tasks may require a similar amount or even more practice by operators in order to reach a desired level of stabile performance prior to comparison testing.

In several important aspects of implementation (i.e., image resolution, contrast, channel registration and crosstalk, system magnification), the precision and quality of the stereo TV display used in this study falls somewhat short of the current state-of-the-art for stereo TV displays exemplified by other presentations on new hardware systems given at this conference. However, the main purpose of the effort described here was not to assess the relative merits of the particular stereo TV display or the manipulator used. Rather, it was to refine test methods in order

to make more precise measures of the impact of system features on overall remote manipulator system performance. Given a sensitive, unbiased testing methodology, a practiced pool of operators, a state-of-the -art force-feedback manipulator, a clear-cut task, diffuse illumination of the taskboard, and an "adequate" stereo TV viewing system , it was possible to show a highly significant performance advantage for stereo TV over a directly comparable mono TV viewing system. Though the demonstrated PiH speed advantage for stereo TV is less than that shown by a previous experiment at NOSC using a similar stereo TV display [9] , the main findings of that earlier experiment were replicated and confirmed here. Movement times, in general, were roughly 3 to 4 times longer for the earlier study. Some of this discrepancy can be attributed to the practice operators received as well as the complexity of the PiH task used. The previous study required operators to grasp the peg prior to moving it from one hole to another. Improvements in stereo TV equipment can reasonably be expected to yield improvements in measured performance of tasks like the one employed here, but to reveal these differences as statistically significant effects will be increasingly difficult without a test method that is sensitive to differences when they occur.

The finding of no significant effect for taskboard orientation on PiH task performance was unexpected given the assumption that , other factors being equal, the more predictable a task, the more efficiently it should be performed. Lack of a significant interaction between taskboard orientation and TV viewing condition was also surprising due to the expectation that stereo viewing would provide the operator with a more accurate perception of the slant of the taskboard and that this would, in turn, allow him/her to make more accurate gross positioning and precision insertion movements. One possibility for the lack of any significant findings is suggested by data from a follow-on (as yet unpublished) experiment. When taskboard orientation was varied in a more extreme manner (i.e., to 10° and 20° deviations off-normal), a modest, but statistically significant main effect was shown in the predicted direction, but no interaction with viewing condition was found. Other explanations can only be speculated about at present due to a lack of performance data. Another possibility, based on the observation that one good, clear view or physical contact with the board might be sufficient to provide the operator with an accurate impression of its position and orientation is suggested by Merritt [10]. By inserting the peg into the START hole , the operator would gain considerable information about the position and orientation of the END hole by correctly assuming that the surface of the taskboard was flat. Throughout the entire experiment detailed here, the averaged depth of the board was unchanged from trial-to-trial. Only its orientation, or slant angle changed, while the position of its center point remained fixed at a constant depth from the cameras. Further studies are underway at NOSC to characterize the effects of positional uncertainty on manipulator performance.

Results from the comparison between performance under direct vs stereo TV viewing conditions suggest, but do not conclusively prove, that black-and-white, NTSC standard stereo TV does, in some circumstances, produce performance that is superior to that achievable under comparable direct viewing conditions. Moreover, results also suggest that the vantage point from which a task is attempted may be equally, or even more important than some aspects of the viewing system that are considered to be critical to system performance.

Finally, the results of the comparison of performance between the human hand and the manipulator again document the considerable gap that separates manipulator performance from direct performance of the task - even when viewing conditions are "equally-natural", though not directly comparable with respect to vantage point.

6. ACKNOWLEDGMENTS

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Inc provided many stimulating ideas and practical suggestions for needed improvements via correspondence and numerous telephone conversations. My deepest appreciation and thanks are certainly due the 8 volunteer operators who spent many hours each performing the monotonous PiH task with pink noise blaring in their ears. Special thanks are also due Mssrs. Seth Sakamoto and Miles Nagato, students from the University of Hawaii's Department of Electrical Engineering, who assisted in data collection and continue to keep the lab facility in good running condition.

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